Investigation of 3D DDA for Application in Rockfall

Rockfall, 3D DDA, Motion Mode

Kyushu University, Student Member L. Zheng
Kyushu University, International Member G. Chen
Kyushu University, International Member K. Zen
Kyushu University, International Member K. Kasama

1 Introduction

Rockfalls are frequent major hazards in mountainous areas. They are relatively small landslides consist of rock fragments from a cliff, or boulders from a slope that bounce, roll, and slide down over the slope surface and finally come to rest. Despite their limited volumes (Rochet, 1987), rockfalls are characterized as high energy during travelling at a rapid speed after the detachment. And rockfall is hardly unpredictable and occured without warning. Therefore, rockfall is potential high-threat in both properties and lives within the run-out. Thus rockfall hazard and risk assessment are particularly important.

To detect accurate risk zone and set protective measures against rockfall, it is important to characterize a particular rockfall by its trajectories of rock fragments or boulders and energies varied both the spatial and the temporal.

One way to investigate the potential hazard of falling rocks is to carry out field experiments. This method is methodologyly undoubtedly valid, but unfortunately it is time and labour consuming especially if it is required for a large scale investigation. An alternative is to simulate the rockfall process using computer models.

Although literature review shows that various factors were reported as triggers of rockfall, in most cases, rockfall movement is determined by a combination of topographical and geological factors. Hence most rock masses are discontinuous by nature, dynamic simulation using the discontinuous deformation analysis - DDA (Shi, 1988) combination with GIS is useful for investigating rockfall characteristics.

In this paper, first a literature review of previous computer models for rockfall was carried out. It indicates that it could evaluate rockfall process more realistically and accurately using 3D DDA with GIS comparing to current models. Then before applying an extension 3D DDA to complicated problems, some simple model tests based on the most important modes of rockfall motion respectively were carried out to verify the applicability of the method.

2 Previous Rockfall Simulation Programs

Since 1976, a large variety of computer programs have been implemented to simulate rockfall process, as shown in Table 1.

These models may be basiclly divided into two groups according to the spatial dimensions considered: 2D models and 3D models. The 2D models are limited in spatial represetation of topographic factors. Consequently, lateral movements were not simulated. Thus the 2D profile selection is critical to obtaining realistic analysis results when using 2D rockfall models. Since it is largely subjective, 2D rockfall models could lead to unacceptable errors.

Table 1 Previous rockfall models

Year	Author(s)	2D / 3D	Rock representation
1976	Piteau and Clayton	2D	Lumped mass
1986	Bozzolo and Pamini	2D	Hybrid
1987	Descoeudres and	3D	Rigid body
1987	Spang	2D	Hybrid
1988	Hungr and Evans	2D	Lumped mass
1989	Pfeiffer and Bowen	2D	Lumped mass
1990	Kobayashi et al.	2D	Hybrid
1991	Zinggeler et al.	2D	Hybrid
1993	Evans and Hungr	2D	Lumped mass
1994	Budetta and Santo	2D	Lumped mass
1994	Chau et al.	2D	Lumped mass
1994	Chen et al.	2D	Lumped mass
1995	Azzoni et al.	2D	Hybrid
1995	Spang and Sönser	2D	Hybrid
1998	Gascuel et al.	3D	Rigid body
1998	Koo and Chern	2D	rigid body/ multiple rigi
1998	Stevens	2D	Hybrid
1999	Donzé et al.	3D	Multiple rigid rock bodi
2000	Jones et al.	2D	Hybrid
2002	Guzzetti et al.	3D	Lumped mass
2003	Dorren and Seijmonsbergen	3D	Lumped mass
2003	Quétel et al.	3D	Rigid Body
2003	Schweigl et al.	2D	Lumped mass
2004	Dorren et al.	3D	Lumped mass
2004	Le Hir et al.	3D	Rigid body

And current models can also be roughly divided into two types: those considering a falling rock with mass concentrated in one point (Lumped mass) and those considering as an rigid body such as rectangle, circle or ellipsoid. The latter models are generally better.

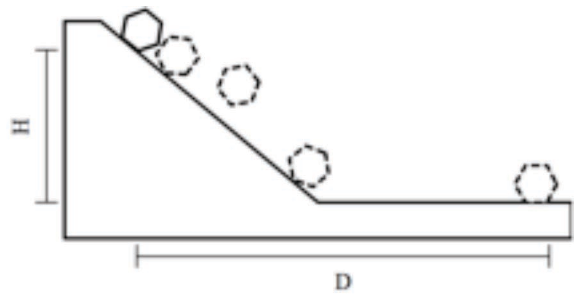


Fig. 1 Block rolling down on an incline.

But in field, rock fragments and boulders are quite different. And by a simple simulation in 2D DDA as shown in Fig. 1, it indicates the run-out distance is largely affected by the shape of block (Fig. 2). Therefore, the over-simplified rock shape in previous is possibly performed unrealistic falling motions.

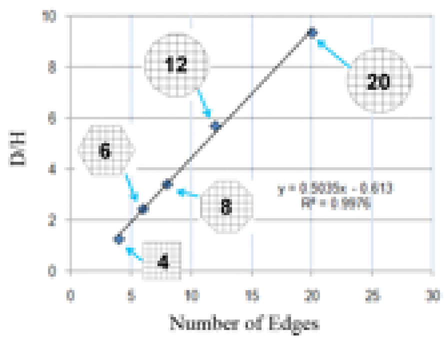


Fig. 2 Shape effect on Run-out distance.

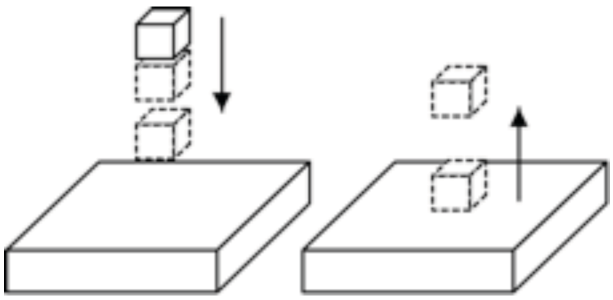
Thus rockfall process is largely influnced by both topograph and rock presentation. So it is important to implement the rockfall simulation using DDA with GIS.

3 Rockfall motion modes and 3D DDA behaviors

For each motion mode, a simple model was carried out to verify 3D DDA application.

Freefall: Freefall of rocks occurs due to a sharp variation in gradient or rebounding after impacting to the slope. During this phase, rocks are translating and rotating in the air, without any contact with slope.

Impact and Rebound: When the trajectory of falling rock intersects the slope surface, an impact happens and a loss of energy should be considered. The simulation are using model in Fig. 3 and parameters in Table 2.



a. Impact　　　　b. Rebound

Fig. 3 Test model for Freefall and Impact.

Rolling and Sliding: When rock moves near or on the slope surface, rolling and sliding happens. Rolling is energy-economic and sliding is the major energy consuming to set the rock rest.

A sliding box on an incline shown in Fig. 5 can be used to investigate the applicability of 3D DDA. Simulation uses the same parameters with friction angle $\phi = 10°$.

Table 2 Parameters used in DDA simulations

Parameter	Value
Density (Kg/m^3)	2000
Young’s modulus (Pa)	1011
Poisson’ ratio	0.1
Penalty	109
Time step (Sec)	0.01

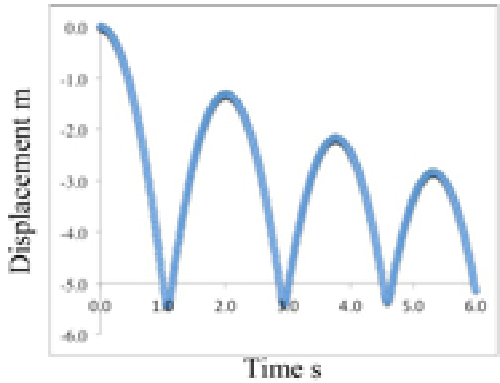


Fig. 4 Displacement vs time in impacting and rebounding.

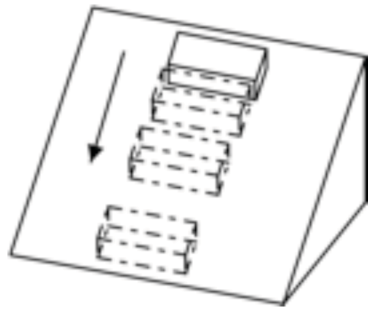


Fig. 5 Box sliding on an incline.

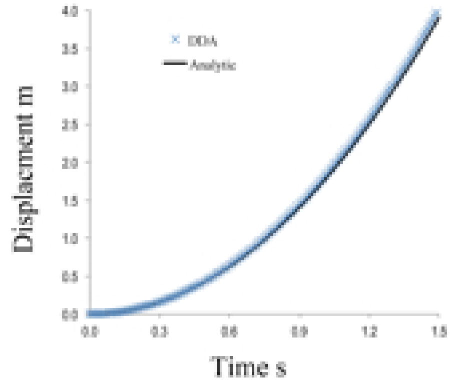


Fig. 6 Displacement vs time in sliding on an incline.

The result is shown in Fig. 6. It is in good agreement with analytic result.

These simulations show that 3D DDA is appropriate to be used to simulate all the rockfall process phases.

4 Conclusions

Since the representations of rock and slope in previous rockfall models are over-simplfied and possibly cause unaccepted results, 3D DDA for rockfall simulation with GIS support is quite important. According to the results, the applicablity of 3D DDA for rockfall is verified in this papers.

Reference

Dorren, L.K.A. 2003: A review of rockfall mechanics and modelling approaches. *Progress in Physical Geography* **27(1)**, 69-87.